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DISTRIBUTION, ABUNDANCE, AND HABITAT USE OF SINGING MALE BOREAL OWLS IN NORTHEAST MINNESOTA

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Abstract.—Compared to other portions of their breeding range, little is known regarding distribution, abundance, and habitat use of Boreal Owls (*Aegolius funereus*) at the southern extent of the boreal forest in eastern North America. To locate Boreal Owls and evaluate abundance and habitat use, we conducted nocturnal surveys for singing male owls in northeast Minnesota from 1987–92. Vocalizing owls were detected on 234 occasions in almost 5000 km of surveys, with 172 (73.5%) of the detections categorized as unique (i.e., individual owls) and 62 (26.5%) detections categorized as owls previously detected (heard during ≥1 previous survey effort). The rate of encounter of singing owls ranged from a low of 0.030 owls/km surveyed in 1987 and 1991 to a high of 0.089 owls/km surveyed in 1989. Indices of abundance based on unique detections ranged from 0.060 owls/km of survey route in 1987 to 0.219 owls/km of survey route in 1989, and minimum density estimates ranged from 0.014 (1987) to 0.051 (1989) singing male Boreal Owls per km^2. No trends in abundance, except an apparent peak in abundance in 1989, were evident across years, although high spatial variation constrained our ability to detect trends. Singing male Boreal Owls used older, upland-mixed-forest stands greater than expected based on availability along survey routes and open/brush/regenerative stands significantly less than expected for courtship activities.

Key Words: *Boreal Owl*; Aegolius funereus; *nocturnal surveys*; *distribution*; *nesting habitat.*

Distribución, abundancia y uso de habitat de buhos boreales en el noreste de Minnesota

Resumen.—Comparado con otras proporciones del rango de reproducción, poco se conoce de la distribución, abundancia y uso de habitat de *Aegolius funereus* en la porción sur del bosque boreal en el este de América del Norte. Para ubicar los buhos boreales y evaluar la abundancia y uso de habitat, hicimos conteos nocturnos para machos vocalizando en el noreste de Minnesota desde 1987–92. Las vocalizaciones de los buhos fueron detectadas en 234 ocasiones en casi 5000 km, con 172 (73.5%) de las detecciones clasificadas como únicas (i.e., buhos individuales) y 62 (26.5%) de las detecciones clasificadas como buhos previamente detectados (escuchados durante esfuerzos de conteo previos). La tasa de encuentros de buhos vocalizando varió de muy baja 0.030 buhos/km recorridos en 1987 y 1991 a alta de 0.089 buhos/km investigados en 1989. Los índices de abundancia se basaron en detecciones únicas que variaron de 0.060/km de las rutas en 1987 a 0.219 buhos/km en las rutas de 1989, los estimativos mínimos de densidad variaron de 0.014 (1987) a 0.051 (1989) de buhos machos que vocalizaron por km. No hubo tendencias de abundancia con excepción de un pico aparente en 1989, (esto fue evidente a traves de los años) aunque la variación espacial constriñó nuestra habilidad para detectar tendencias. Los buhos machos que vocalizaron usaron bosques mixtos de altura mas de lo esperado con base en su disponibilidad a lo largo de las rutas de investigación. Los rodales abiertos de arbustos en regeneración fueron significativamente menos utilizados que lo esperado para actividades de cortejo.

[Traducción de César Márquez]

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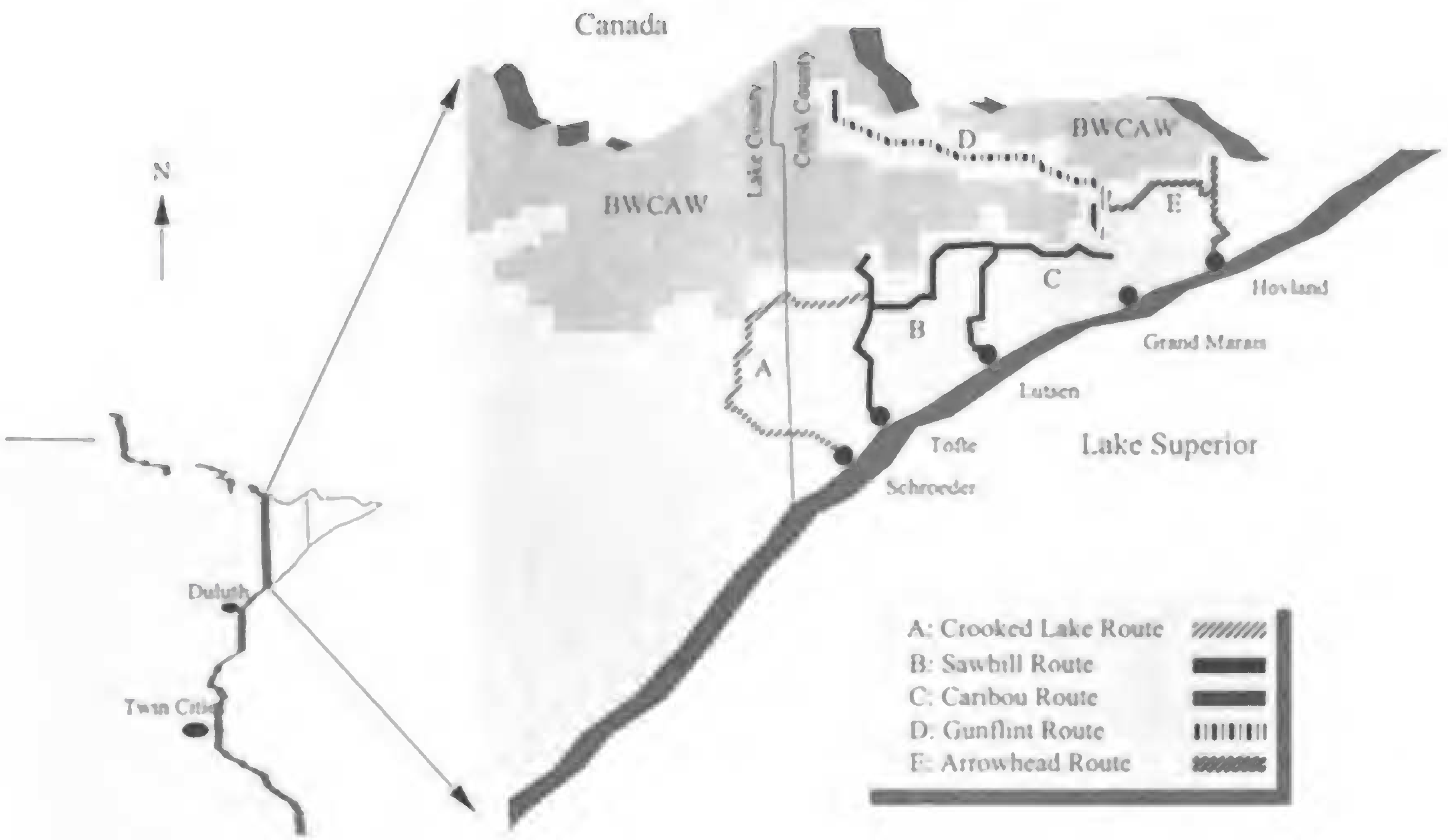

Figure 1. Study area and location of five survey routes for singing male Boreal Owls (*Aegolius funereus*) in northeast Minnesota from 1987–1992.

Boreal Owls *(Aegolius funereus)* have a holarctic distribution (as Tengmalm's Owl in Europe and Asia) and occur as a breeding species throughout the boreal forest zone of North America and within alpine variants of the boreal forest in the Rocky Mountains (American Ornithologists' Union 1998). Nocturnal surveys to locate breeding Boreal Owls during the spring have been used in North America to describe the species' distribution, population status, and habitat requirements (Bondrup-Nielsen 1978, Eckert and Savaloja 1979, Meehan 1980, Hayward and Garton 1983, Palmer and Ryder 1984, Palmer 1986, O'Connell 1987, Lane 1988, Hayward 1989, Holt and Ermatinger 1989, Whelton 1989, Stahlecker and Rawinski 1990). Results of these surveys indicate that in western North America, Boreal Owls are more common than previously thought, and that they exhibit preferences for both homogeneous conifer forests and mixed stands of conifers and aspen (*Populus* spp.) during the breeding season (Hayward 1994). Considerably less information is available regarding Boreal Owl breeding distribution and habitat use in eastern North America. Most observations of Boreal Owls in eastern North America have occurred during irregular wintertime irruptions south of the boreal forest (Roberts 1932, Bent 1938, Green 1966, 1969, Catling 1972, Eckert 1982, 1989, 1992). Relatively few studies of Boreal Owls have been conducted during the breeding season (see Bondrup-Nielsen 1978, Lane 1997) within the southern extent of the boreal forest in eastern North America.

Beginning in 1987, we initiated an investigation to determine if Boreal Owls could be located during the breeding season, and if so, to provide seasonal indices of abundance and characterize habitat associated with breeding in Minnesota. We report herein on the results of a 6-yr study (1987–92) to document distribution, abundance, and habitat use by singing male Boreal Owls in northeast Minnesota.

STUDY AREA AND METHODS

The study was conducted in the northeast portion of Minnesota, within Cook County and along the eastern portion of Lake County (Fig. 1). Lake and Cook counties together extend over an area of approximately 800 000 ha, the majority of which is contained within the Superior National Forest (SNF), which includes the Boundary Waters Canoe Area Wilderness (BWCAW). Approximately 80% of the land area is forested and nearly 18% is covered by water bodies. Urban or developed land is minimally represented (Spadaccini and Whiting 1985).

The area is geologically defined by exposed Precambrian bedrock to the north (Border Lakes Region) and by the Sawtooth Mountain Range (along the north shore of Lake Superior) to the south, while the central portion is dominated by thick glacial drift that covers all but the most prominent structural features (Austin 1961). The climate in northeast Minnesota is influenced by seasonally generated Continental and Pacific air masses and is dominated during the winter by strong Arctic flows. Severe winters and an average annual snowfall of 152 cm counter mild summers with a short growing season (May–September) and an average rainfall of 45 cm. The mean temperature in the region ranges from −17°C in January to 17°C in July, and snow remains on the ground in most years well into April (Ahlgren 1969).

Northeast Minnesota supports three types of forests. The southernmost extent of the boreal forest (Rowe 1972) extends into northeast Minnesota and is characterized by balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), white spruce (*Picea glauca*), quaking aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). The boreal forest is transitional to the broadleaf, deciduous forest to the south and west (Larsen 1980), which in the study area is characterized by sugar maple (*Acer saccharum*) along the Sawtooth Mountain Range, and minimally by yellow birch (*Betula alleghaniensis*). Farther east, white pine (*Pinus strobus*) and red pine (*Pinus resinosa*) characterize the Great Lakes-St. Lawrence forest (Rowe 1972). Combined, pockets of boreal, northern hardwood, and pine forests persist regionally, although fire, fire suppression, and timber harvest have had considerable influence in shaping the present-day forest mosaic (Heinselman 1973). Aspen in particular has benefitted from anthropogenic disturbances, and the management of aspen as a pulp resource is encouraged by silvicultural practices within the study area (Superior National Forest 1986). When compared to the forests present in northern Minnesota at the time of European settlement (Flader 1983), forests today are characterized by both diminished tree-species diversity and a homogeneity of forest ages (Mladenoff and Pastor 1993).

Surveys and Survey Routes. From 1987–92, we conducted nocturnal auditory surveys (Bondrup-Nielsen 1978, Holmgren 1979, Palmer 1986) to locate vocalizing Boreal Owls. We listened for the broadcast staccato song of male owls (Bondrup-Nielson 1984) along established survey routes. This vocalization is usually made from within 100 m of a nest cavity to attract females (Hayward and Hayward 1993) and is the loudest vocalization of the species, with a range of detection approaching 3.5 km (Bondrup-Nielsen 1984).

We concentrated survey efforts within the eastern portion of the SNF, and in areas that included documented nesting attempts by Boreal Owls (Eckert and Savaloja 1979, Eckert 1979, Matthiae 1982). Surveys were conducted from roads that were maintained for wintertime access by motor vehicles and traversed all habitats found within the study area. Five survey routes were used throughout this study (Fig. 1). During surveys conducted from 1987–89, the average route length was 60.9 km (range = 41.9–71.7 km). Following the 1989 field season, an assessment of the previous distribution of Boreal Owls was made based on 1987–89 survey results, and portions of each route where vocalizing owls had not been detected (primarily deciduous uplands along the Sawtooth Mountain Range) were eliminated, reducing the average route length to 48.6 km (range = 38.0–62.6 km). During 1992, two routes (Gunflint and Arrowhead) were not surveyed. Instead, the three remaining routes (Crooked Lake, Sawbill, and Caribou) were divided in half and treated as six individual routes ($\bar{x}$ = 21.5 km, range = 15.7–27.4 km).

In all years, surveys were initiated prior to the end of March (range = 16 February–23 March) and ended by mid-May (range = 8 April–14 May), with >50% (range = 52–100%) of surveys each year being conducted between 15 March–30 April. Individual surveys were initiated at least ½ hr after sunset and continued until the route was completed or daylight occurred. Surveys were not conducted in moderate to heavy precipitation or in winds exceeding 23 km/hr. If weather conditions deteriorated while a route was being surveyed and <½ of the route was completed, we waited for at least 1 hr before abandoning surveys for the evening. We continued the abbreviated route during the following evening, or when conditions again were conducive for detecting singing owls. Survey efforts with >½ of the route surveyed when interrupted by deteriorating weather conditions were not completed subsequently.

At 0.8-km intervals, we listened for 3 min for vocalizing Boreal Owls. When an owl was heard, we recorded the direction to the bird and estimated the distance qualitatively (i.e., barely perceptible, moderate, loud). Additional directions from subsequent listening stations were recorded for owls heard at previous stops to triangulate the owls' locations. The estimated locations of owls detected during initial surveys were plotted on U.S. Geological Survey (USGS) 1:24 000 topographic maps. If on subsequent surveys, an owl was heard calling from within 1.6 km of where an owl had previously been heard calling on a previous survey (based upon Minimum Convex Polygon [MCP] home range size; Lane 1997), we categorized it as the same individual, unless there was evidence of more than one owl at a given location (i.e , multiple simultaneous vocalizations).

To make our results directly comparable with results from other nocturnal owl surveys, we calculated an encounter rate based on all owl detections. Annual encounter rates were calculated by summing the total number of owl detections and dividing by the total km surveyed along the five routes combined, and along each individual survey route. We also derived an index to abundance based on the cumulative number of individual owls located along each survey route. Annual abundance indices were calculated by dividing the total number of unique detections along each route by the length of that route. For 1992 data, annual abundance indices were calculated by combining the two segments of routes that previously had been surveyed as a single route. To make data comparable through time, the portions of each route that were eliminated after 1989 were not included in calculations for any year. Finally, we estimated minimum density of singing male Boreal Owls based on the number of individual owls whose locations were estimated to be <2 km from survey routes, divided by the area estimated to be <2 km from survey routes. Ninety-two percent of singing owls detected were <2 km from the

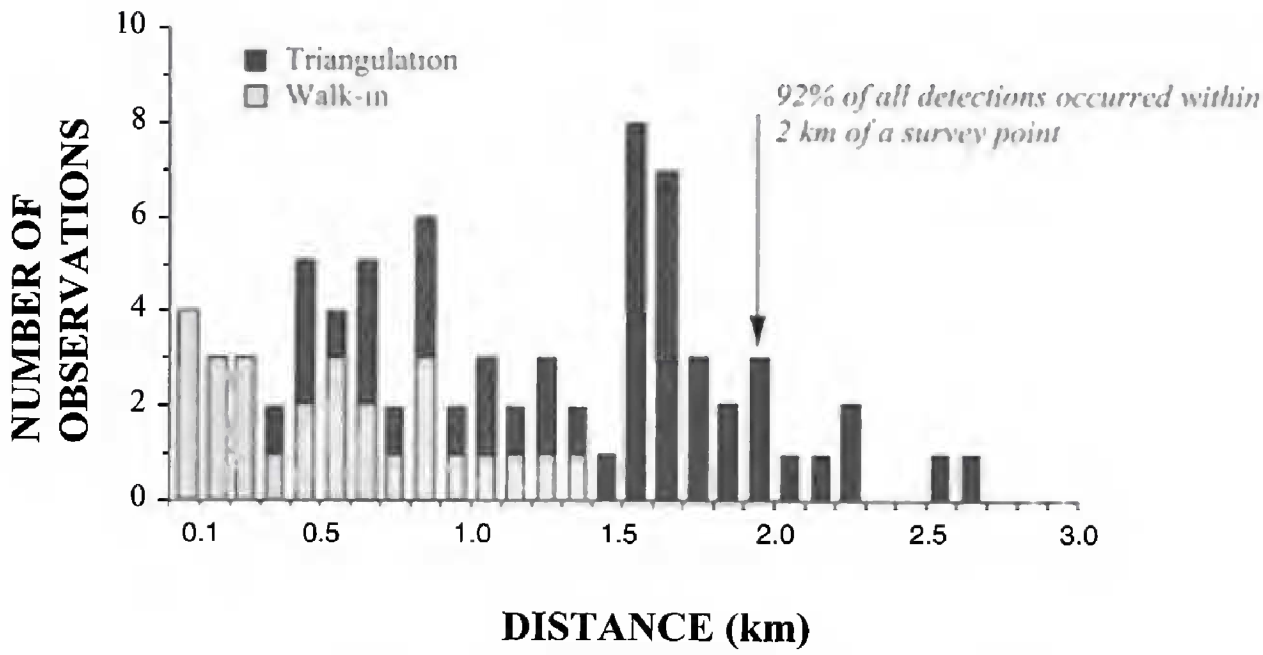

Figure 2. Frequency distribution of the estimated distances of owl locations from points along survey routes for singing male Boreal Owls (*Aegolius funereus*) in northeast Minnesota from 1987–1992. "Triangulation" consisted of estimating owl locations via directional azimuths from multiple points along survey routes and "walk-in" consisted of on-the-ground searches.

survey route, with no obvious decrease in detection frequency beyond this distance (Fig. 2). The area along survey routes was estimated by multiplying the length of the route by 4 km (2 km on either side of the route) and adding the area within 2 km at the ends of the routes.

Location of Boreal Owls and Available Habitat. On-the-ground searches to identify stands or potential nesting cavities were conducted for a portion of owls heard calling beginning in 1988. During 1988, on-the-ground search efforts were restricted to birds <0.6 km from survey routes, reflecting our unfamiliarity with both the owl and the study area. Thereafter (1989 and beyond), foot search effort largely depended upon the type of vocalizations heard, and were primarily directed toward locating nest sites. For instance, if a singing male was heard during surveys, it was monitored for several nights in an attempt to detect vocalizations that indicated a female was present (i.e., prolonged staccato, Bondrup-Nielsen 1984), prior to determining the owl's location via an on-the-ground search.

In combination with aerial photographs and U.S. Forest Service (USFS) compartment maps (both 1:15 840), we estimated the locations of owls within forest stands. To estimate habitat abundance along survey routes, we first constructed a frequency distribution of distances of owls from survey routes, based on triangulation estimates of owl locations from survey points and on distances from detection points to known locations (identified by on-the-ground searches). Based on this distribution of detection distances, we used a scaled 4-km^2 grid (based upon a 2.0-km detection distance in each cardinal direction from a survey point) to measure habitat abundance along each of the five survey routes. Sampling locations were determined randomly by multiplying the route length by a series of randomly-generated numbers between 0 and 1, and centering the 4-km^2 grid on the resulting point. If two grids overlapped, we selected another random number and repeated this process until grids did not overlap.

We used two methods to obtain habitat data for survey routes. For the western portion of our study area within the Tofte Ranger District (SNF), a 4-km^2 mylar overlay was placed atop USFS compartment maps. Individual stand data within the grids were extracted from Timber Stand Inventory (TSI) records. If a stand transected the grid border, an estimate of area within the plot was made using a modified area grid. Water body area was estimated in a similar manner, using both USFS data and dot-grid estimates. In the eastern portion of our study area within the Gunflint Ranger District (SNF), random habitat grid locations and four Universal Transverse Mercator (UTM) coordinates (representing the corners of each 4-km^2 habitat grid) were established. USFS TSI data stored in ARC-INFO® were extracted and transferred into an electronic database. For both the western and eastern portions of our study area, habitat data under state ownership were extracted from R-Data Base® files and converted for compatibility with USFS data. Habitat abundance in grids that included private land ownership or that were within the BWCAW (no compartment data available) was evaluated using aerial photographs in conjunction with adjacent stand information.

For our analysis, we compiled three variables included in TSI data; area, Forest Survey Type (FST), and Stand Size Density (SSD). Forest Survey Types were grouped into seven categories: upland conifer, upland-mixed (conifer-deciduous tree component), upland hardwood, lowland conifer, lowland-mixed, lowland hardwood, and open/brush, with permanent water bodies comprising an eighth category (Table 1). Three density classes were used for analysis: Density 1 included water bodies and open areas and represented minimal or regenerating forest vegetation; Density 2 included poletimber; and Density 3 included sawtimber-sized forest tracts. The proportion of each habitat type and density was tabulated on both a per grid and per route basis. Habitat data depicted forest characteristics present in the study area in 1992, and did not account for change in the composition of habitats along survey routes from 1987–92. We were

Table 1. Dominant tree species of Forest Survey Types occurring in the study area and used to categorize habitats along five survey routes used to detect Boreal Owls (*Aegolius funereus*) in northeast Minnesota from 1987–92. Habitat types were categorized according to USDA Forest Service (1972) and Minnesota Department of Natural Resources (1981) guidelines.

Forest Survey Type	Dominant Tree Species	Scientific Name
Upland conifer	jack pine	*Pinus banksiana*
	red pine	*P. resinosa*
	white pine	*P. strobus*
	white spruce	*Picea glauca*
	black spruce (upland)	*P. mariana*
	balsam fir	*Abies balsamea*
Upland-mixed	balsam fir	
	aspen	*Populus* spp.
	paper birch	*Betula papyrifera*
	white spruce	
Upland hardwood	quaking aspen	*P. tremuloides*
	paper birch	
	sugar maple	*Acer saccharum*
	American basswood	*Tilia americana*
	yellow birch	*B. alleghaniensi*
	red maple (upland)	*A. rubrum*
	balsam poplar	*P. balsamifera*
Lowland conifer	black spruce	
	white cedar	*Thuja occidentalis*
	tamarack	*Larix laricina*
Lowland-mixed	white cedar	
	aspen	
	paper birch	
Lowland hardwood	black ash	*Fraxinus nigra*
	American elm	*Ulmus americana*
	red maple	
Open/Brush	lowland brush	
	upland brush	
	open	

aware of some changes in habitat composition along routes during the study period (e.g., harvest activities), but felt that these changes did not appreciably affect the proportion of each habitat category within the study area.

We used Chi-square goodness-of-fit tests and Bonferroni confidence intervals (Neu et al. 1974, Byers et al. 1984) to determine if a difference ($\alpha \leq 0.05$) existed between observed habitat use by Boreal Owls and expected use based on habitat abundance. Habitat abundance was determined by pooling habitat composition across routes to provide a composite summary of habitat abundance within the study area. Habitat use was determined by identifying the forest stands (restricted to owl locations determined by on-the-ground searches) supporting vocalizing owls. Because all observations of singing owls used for this analysis occurred in forested tracts, we eliminated nonforested categories (Density 1) and performed a second Chi-square analysis on habitat use based only on Density 2 and Density 3 data. We use terminology regarding habitat consistently with that suggested by Hall et al. (1997).

We tested for effects of year on encounter rate using one-way analysis of variance (ANOVA) with routes as replicates, and tested for evidence of spatial and temporal differences in encounter rates and abundance indices using two-way ANOVA. We compared encounter rates and abundance indices with paired-t tests and, for years when the number of individual owls detected was sufficient, we compared the distribution of owls among survey routes with a χ^2-test weighting owl distribution by length of survey routes. All statistical tests were conducted following procedures outlined in Snedecor and Cochran (1980) and Gibbons (1985).

RESULTS

From 1987–92, singing male Boreal Owls were detected on 234 occasions along 4998.2 km of surveys, averaging 0.047 detections/km surveyed.

Table 2. Encounter rate, abundance indices, and minimum density of singing male Boreal Owls (*Aegolius funereus*) located along survey routes in northeast Minnesota from 19876–92. In 1992, the Gunflint and Arrowhead routes were not surveyed.

YEAR	SURVEY ROUTE	km SURVEYED[1]	TOTAL OWLS	ENCOUNTER RATE[2]	ABUNDANCE INDEX[3]	MINIMUM DENSITY[4]
1987	Crooked Lake	142.8	1	0.007	0.025	0.005
	Sawbill	146.3	4	0.027	0.078	0.017
	Caribou	72.7	5	0.069	0.132	0.028
	Gunflint	61.5	1	0.016	0.016	0.004
	Arrowhead	101.6	5	0.049	0.068	0.015
	Totals (mean)	524.9	16	(0.034)	(0.064)	(0.014)
1988	Crooked Lake	156.4	7	0.045	0.172	0.037
	Sawbill	206	6	0.029	0.097	0.017
	Caribou	132.7	1	0.008	0.026	0.000
	Gunflint	226.8	21	0.093	0.240	0.047
	Arrowhead	204	6	0.029	0.085	0.019
	Totals (mean)	925.9	41	(0.041)	(0.124)	(0.024)
1989	Crooked Lake	186.1	17	0.091	0.271	0.063
	Sawbill	206	17	0.083	0.194	0.041
	Caribou	152	14	0.092	0.231	0.055
	Gunflint	249.4	32	0.128	0.304	0.072
	Arrowhead	200.2	8	0.040	0.102	0.024
	Totals (mean)	993.7	88	(0.072)	(0.220)	(0.051)
1990	Crooked Lake	146.5	4	0.027	0.099	0.023
	Sawbill	134.7	5	0.037	0.097	0.023
	Caribou	50	3	0.060	0.079	0.018
	Gunflint	102.9	5	0.049	0.064	0.015
	Arrowhead	78.4	1	0.013	0.017	0.004
	Totals (mean)	512.5	18	(0.037)	(0.071)	(0.017)
1991	Crooked Lake	264.5	12	0.045	0.197	0.040
	Sawbill	247.3	9	0.036	0.136	0.032
	Caribou	186.4	5	0.027	0.079	0.018
	Gunflint	218.8	5	0.023	0.080	0.019
	Arrowhead	256.9	4	0.015	0.068	0.012
	Totals (mean)	1173.9	35	(0.029)	(0.112)	(0.024)
1992	Crooked Lake	293.2	12	0.041	0.222	0.046
	Sawbill	362.2	18	0.050	0.252	0.055
	Caribou	211.9	6	0.028	0.079	0.018
	Totals (mean)	867.3	36	(0.040)	(0.184)	(0.040)

[1] Includes only survey efforts along revised routes (see text).
[2] Owl detections/total km surveyed.
[3] Number of individual owls detected/km.
[4] Number of individual owls per km^2, estimated based on owl detections within 2 km of survey routes.

Based on the total number of owl detections during all surveys, encounter rates were lowest in 1987 and 1991 (0.030 detections/km) and highest in 1989 (0.089 detections/km). Fifteen (0.060 owls/km) individual owls were detected along survey routes in 1987 and 55 (0.219 owls/km) owls were detected in 1989.

Distribution. Boreal Owls were detected along all five survey routes in 1987–91, and along the three routes where surveys were conducted in 1992 (Table 2). During the five years that all five routes were surveyed (1987–91), there were no apparent patterns in encounter rate as a function of either year (two-way ANOVA, $F_{4,16} = 1.98$, $P = 0.146$) or route ($F_{4,16} = 1.37$, $P = 0.288$). Indices to abundance (individual owls/km of survey route) varied among years ($F_{4,16} = 5.66$, $P = 0.005$) but not routes ($F_{4,16} = 1.55$, $P = 0.234$). The numbers of

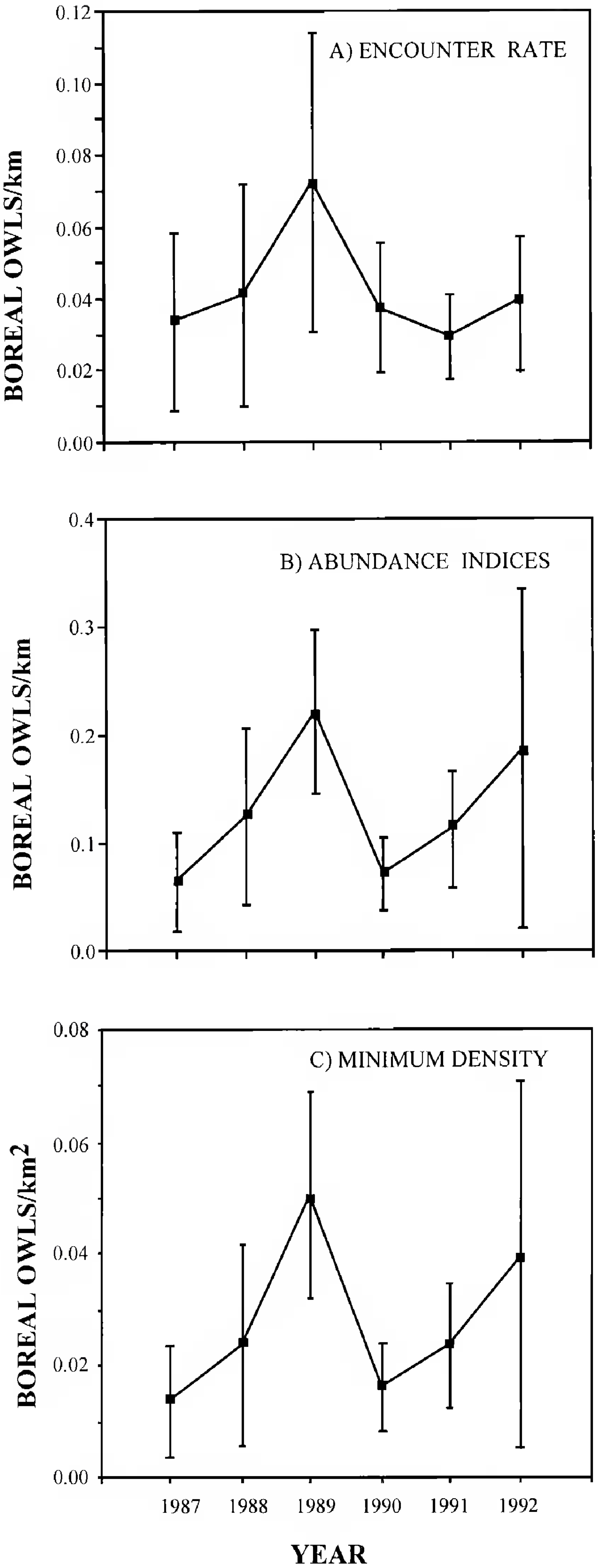

Figure 3. Encounter rates (A), abundance indices (B), and minimum density estimates (C) for singing male Boreal Owls (*Aegolius funereus*) detected along five survey routes from 1987 through 1991 and three survey routes in 1992 in northeast Minnesota. Error bars represent 90% Confidence Intervals using survey routes as replicates.

owls detected along survey routes in 1988, 1989, 1991, and 1992 were high enough to allow Chi-square analysis of distribution of owls among routes. Only in 1988 (χ^2 = 10.75, $P < 0.05$) were owl detections distributed among routes differently than expected based on route length, with more owls detected than expected along the Gunflint route and fewer than expected owls detected along the Arrowhead route.

Abundance. Average annual encounter rate (based on routes as replicates) varied from 0.029 detections/km in 1991 to 0.072 detections/km in 1989 (Table 2, Fig. 3). However, there was no evidence of a statistically significant difference among years in encounter rate, based on surveys as replicates (one-way ANOVA, $F_{4,23}$ = 1.16, P = 0.353), or when including route as a factor in statistical analyses (two-way ANOVA, $F_{4,16}$ = 1.98, P = 0.146). Average abundance indices were lowest in 1987 (0.064 owls/km) and highest in 1989 (0.220 owls/km), with an apparent peak in abundance in 1989 (two-way ANOVA, $F_{4,16}$ = 5.66, P = 0.005; Fig. 3). Unique (individual) owl detections comprised 172 (73.5%) of 234 total detections across years and ranged from 62.5% of all detections in 1989 to 94.4% in 1990. Abundance indices were significantly higher than detection rates (paired-t_{27} = 7.07, $P < 0.0001$) when all year-route combinations were treated as independent observations. Minimum estimated density of singing male Boreal Owls along survey routes ranged from 0.000 owls/km^2 (Caribou route 1988) to 0.072 owls/km^2 (Gunflint route 1989), and annual averages across routes ranged from 0.014 owls/km^2 (1987) to 0.051 owls/km^2 (1989; Fig. 3).

Habitat Use. The area along survey routes for which habitat abundance was estimated comprised, on average, 34.9% (range = 30.8–47.0%) of the area <2 km from the routes. Upland conifers (range = 10.5–29.9%), upland hardwoods (range = 19.1–38.8%), upland-mixed (range = 16.0–26.3%), and lowland conifers (range = 8.6–13.1%) comprised the largest proportions of forest types along survey routes (Table 3), while lowland hardwoods and lowland-mixed forests were minimally

Table 3. Percent of area by stand size density category and habitat type along survey routes for singing male Boreal Owls (*Aegolius funereus*) in northeast Minnesota from 1987–92.

Survey Route	Density Category			Habitat Type					
	1	2	3	Water/Open/ Brush	Upland Conifer	Upland Mixed	Upland Hardwood	Lowland Conifer	Lowland Mixed/ Hardwood
Crooked Lake	41.2	39.2	19.6	13.7	14.2	22.3	37.7	10.7	1.4
Sawbill	44.5	39.8	15.6	13.9	27.4	21.6	19.1	13.1	4.8
Caribou	31.0	52.0	17.0	14.1	10.5	23.3	38.8	12.4	0.7
Gunflint	32.6	48.5	16.4	13.3	29.9	16	31.5	8.6	0.5
Arrowhead	31.6	41.5	26.9	13.6	12.5	28.3	36.7	8.7	0.0
Mean	36.2	44.2	19.1	13.7	18.9	22.3	32.8	10.7	1.5

represented (each <1%). Density 1 size classifications ranged from 31.0–44.5%, Density 2 from 39.2–52.0%, and Density 3 from 15.6–26.9% of the area along survey routes.

All stands used by Boreal Owls were classified as either Density 2 (poletimber) or Density 3 (sawtimber). Density 1 stands were used significantly less, and Density 3 stands significantly more than expected based on availability (Table 4). Chi-square analysis based solely on Density 2 and Density 3 stands indicated that use of upland-mixed forests by vocalizing Boreal Owls was significantly greater than expected, while use of lowland conifer stands was significantly less than expected based on availability (Table 5).

Discussion

Boreal Owls appear to be widely distributed, occur at low densities (with apparent high among-year variation in number of breeding birds) as a regular breeder, and select older, upland-mixed forests for nesting activities in much of northeast Minnesota. Low breeding densities are also indicated in other parts of the species' North American distribution. For example, Bondrup-Nielsen (1978) reported that Boreal Owl numbers in Kapuskasing, Ontario (160 latitudinal km north of Minnesota) ranged from 1.8 owls per 20 km^2 in 1974 to 0.63 owls per 20 km^2 in 1975. Meehan (1980) located five (0.5 owls per 20 km^2) male Boreal Owls in 1977 and 10 (1.0 owls per 20 km^2) in 1978 in a 200 km^2 Alaska study area, and Palmer (1986) located nine (2.0 owls per 20 km^2) Boreal Owls during 1983 and 27 (6.1 owls per 20 km^2) in 1984 in a Colorado study area of 90 km^2. If we assume near 100% detection of vocalizing owls within 2 km of our survey routes, then annual average (across routes) minimum density estimates for territorial singing male owls in our study ranged from 0.3–1.0 owls/20 km^2.

Most previous studies of Boreal Owls in North America have reported encounter rates rather than estimating a minimum number of individual owls along a survey route. This could, however, result in a biased index of the number of owls in a particular landscape, because not all owls present are likely to be detected on any one survey, and frequency of singing may vary temporally and spatially. Hayward et al. (1993) used on-the-ground searches to identify individual owls and determined that 15 (23.8%) of 63 owls were previously located along established survey routes in Idaho.

Table 4. Proportion of habitat type categorized as Density 1 (open/brush/water), Density 2 (poletimber) and Density 3 (sawtimber) along survey routes, and number of Boreal Owls (*Aegolius funereus*) observed by density category in northeast Minnesota from 1987–92. Habitat abundance is based upon random sampling along five survey routes, pooling across routes. Bonferroni confidence intervals (95%) were constructed to test if habitats were under- or over-represented in use by singing male Boreal Owls. Habitat use is based upon the number of owls ($N = 56$) located along survey routes for which on-the-ground searches were conducted to establish location.

Density Category	Proportion of Total	Number of Boreal Owls		Proportion of Boreal Owls		95% Bonferroni Confidence Intervals	Significance ($\alpha = 0.05$)
		Expected	Observed	Expected	Observed		
Density 1	0.367	20.56	3	0.367	0.036	$0 \le p \le 0.095$	Less use
Density 2	0.442	24.75	17	0.442	0.321	$0.174 \le p \le 0.468$	
Density 3	0.191	10.7	36	0.191	0.643	$0.498 \le p \le 0.798$	Greater use

Because of the scale of our study, we were only able to conduct on-the-ground searches for approximately 25% of the owls heard, and supplemented direct observations with triangulation estimates of owl locations. Because precision in identifying owl locations by triangulation decreased with the distance of an owl from a detection point, we separated owl locations by 1.6 km (i.e., an owl heard on ≥1 subsequent survey within 1.6 km of a previous detection point was considered the same owl). Based on this approach, approximately 26% of owl detections were categorized as previously-detected owls in our surveys.

Abundance of Boreal Owls can vary markedly from year to year and owl movement and reproductive patterns are closely tied to 3–4 yr microtine cycles in some portions of their range (Mysterud 1970, Bondrup-Nielsen 1978, Lundberg 1979, Korpimäki 1986, Palmer 1986, Hayward 1989, Korpimäki and Norrdahl 1989, Hakkarainen and Korpimäki 1994). In the northern latitudes of Europe, Boreal Owls are described as nomadic, microtine specialists but are considered a resident generalist predator to the south (Korpimäki 1986). As a result, European populations are more numerically stable at the southern extent of their distribution and less impacted by vole cycles than owl populations farther north (Korpimäki 1986). Our data suggested temporal fluctuations in abundance of territorial Boreal Owls in northeast Minnesota, with an apparent peak in abundance in 1989. However, variation among routes within years was high (coefficients of variation of estimates of encounter rate, abundance indices, and minimum density ranged from 28–76%), constraining our ability to detect trends in abundance.

The localized distribution of Boreal Owls is directly affected by the availability of preferred habitat features within the landscape. Korpimäki (1986) described both favorable habitat patches and unfavorable inter-patch areas that were either used or avoided by Boreal Owls in Finland. Because our study area was located within a transition area of three types of forests, distinct pockets of boreal forest, deciduous northern hardwoods, and eastern pine forests were widespread. Habitat composition varied considerably across the study area and patterns of use by Boreal Owls were related to the presence of specific habitat types. In areas where older boreal forest (Heinselman 1973) occurred, we regularly found owls. Conversely, we detected few owls in areas not representative of boreal forest, especially in Density 1 forested tracts. In addition, Boreal Owls are secondary cavity users and the abundance and availability of suitable cavities may influence abundance and distribution of owls. Forest management activities that negatively affect older, upland-mixed forest types could influence the distribution of Boreal Owls by reducing the proportion of the landscape that owls seem to prefer. Furthermore, Boreal Owls appear to rely on lowland conifer habitats for foraging and roosting (Lane 1997), suggesting that proximity and juxtaposition of habitat types within this landscape need to be considered in management and conservation strategies for Boreal Owls.

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Table 5. Proportion of habitat type categorized as Density 2 (poletimber) and Density 3 (sawtimber) along survey routes, and number of observations by habitat type for Boreal Owls (*Aegolius funereus*) in northeast Minnesota from 1987–92. Habitat proportions are based upon random sampling along five survey routes, pooling across routes. Bonferroni confidence intervals (95%) were constructed to test if habitats were under- or overrepresented in use by singing male Boreal Owls. Habitat use is based upon the number of owls ($N = 56$) located along survey routes for which on-the-ground searches were conducted to establish location.

Habitat Type	Proportion of Total Area	Number of Boreal Owls		Proportion of Boreal Owls		95% Bonferroni Confidence Intervals	Significance ($\alpha = 0.05$)
		Expected	Observed	Expected	Observed		
Upland conifer	0.187	10.47	8	0.187	0.143	$0.019 \leq p \leq 0.267$	
Upland-mixed	0.297	16.63	30	0.297	0.536	$0.360 \leq p \leq 0.712$	Greater use
Upland hardwood	0.374	20.94	17	0.374	0.304	$0.142 \leq p \leq 0.466$	
Lowland conifer	0.117	6.55	1	0.117	0.018	$0.029 \leq p \leq 0.068$	Less use
Lowland-mixed/ hardwood	0.024	1.34	0	0.024	0	$0.022 \leq p \leq 0.072$	

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